

GEOMORPHOLOGY OF THE LAKE OMEO BASIN, VICTORIA

By R. K. ROWE

Soil Conservation Authority, 378 Cotham Road, Kew, Victoria 3101

Present address: Arthur Rylah Institute for Environmental Research, 123 Brown Street, Heidelberg, Victoria 3084.

ABSTRACT: Lake Omeo is a relic of a more extensive lake formed when a basalt flow, dated as Upper Pliocene in age, dammed the flow of Morass Creek. This larger lake is referred to as Lake Morass. Downfaulting of part of the Lake Omeo basin and upthrow of a narrow horst between the Morass Creek and Minute Creek catchments probably occurred at about the same time or later. Sedimentation of the natural overflow gap of the Lake Omeo basin during the existence of Lake Morass resulted in the basin becoming isolated from Morass Creek as the basalt flow was incised. Clay sediments over 40 m thick were deposited in the downfaulted part of the basin. Two clay lunettes to the southeast of the present lake, and material of fluvial and lacustrine origin provide evidence for alternation between wet periods when high water levels prevailed and dry periods with low water levels during which lunette building occurred. The evidence has been interpreted as indicating major changes in climate in the history of the lake. At least three lunette building phases are proposed, separated by periods of high lake levels. A palaeosol buried beneath a layer of clay of lacustrine origin is ascribed an Upper Pliocene origin.

In this paper a number of unusual features associated with the Lake Omeo basin are described and their origins are examined. An interpretation of the geomorphic history of the area and its significance in relation to Pleistocene environments in this region is proposed.

Lake Omeo, a small ephemeral lake near Benambra in the northeastern highlands of Victoria (Fig. 1), is the focus of an internal drainage basin of about 57 km². The area has a general elevation of about 750 m above sea level, but because of an extensive rain shadow produced by the Mt. Hotham-Mt. Bogong highlands to the west, the average annual rainfall is only about 630 mm. The water level in the lake fluctuates considerably, both seasonally and from year to year. It is often dry for long periods. It reached its highest level in recent times in 1956. No permanent record of lake levels is kept. The 1956 level was apparently slightly higher than the level determined during level surveys in 1960 (Fig. 2) and shown in Figs 7 and 8. Timms (1975) recorded that an earlier "lake full" year was 1896 and Bennett and Schwerdtfeger (1970) presented a collection of statements on the lake's condition over the period from 1870 to the present time. They claimed that lake full condition only occurs in association with periods of above normal rainfall. It is important to note that the term "lake full" in this context does not mean overflow into the adjacent Morass Creek drainage system.

The lake is bordered to the north by a low ridge of granite approximately 2 km long, and to the south and southeast by a low ridge beyond which is an extensive clay plain gently rising to the footslopes of the Dividing Range in the vicinity of The Sisters (Fig. 3). To the west of the lake, the basin rises through rolling to hilly topography to the watershed with the deeply entrenched Reedy Creek, and on the eastern side it is bounded by a narrow, sharply defined low ridge on which the township of Benambra is located. To the north, the

basin extends beyond the granite ridge on the lake shore as a gently rising mature landscape (Fig. 1).

Immediately to the east of the basin is the broad, alluviated valley of Morass Creek which, some 8 km to the north enters a deep gorge dissected through a flow of basalt which filled the ancient valley of the lower Morass Creek and short sections of the Gibbo and Mitta Mitta Rivers.

STRUCTURE OF THE AREA

The earliest published reference to the mode of formation of the lake appears to be a report by D. E. Thomas (1937) who noted several unusual land forms associated with the lake and suggested that it had been formed by stream capture. Thomas reproduced a map of H. S. Whitlaw (previously unpublished), showing a probable fault along the northern edge of the lake, delimiting the granite, and another fault, parallel, but about 0.8 km further north. However, he dismissed faulting as being responsible for the creation of the lake. Furthermore, he considered that the granite ridge was not related to the formation of the lake and suggested that its elevated position resulted from differential erosion.

A report by J. P. L. Kenny (1937) referred to the basalt flow in the lower Morass Creek and agreed with Thomas's suggestion that the Lake Omeo basin was isolated from the Morass drainage by sedimentation of its earlier outlet.

Hills (1975, p. 301) suggested that the lake was probably formed by back tilting of the block west of a north-south fault adjoining Benambra, with the consequent defeating of a tributary of Morass Creek. Talent (1965, p. 122) suggested that faulting which occurred during the Quaternary had played a part in its formation, and later (1969, p. 53) he described the long low ridge of sedimentary rock on the eastern boundary of the basin

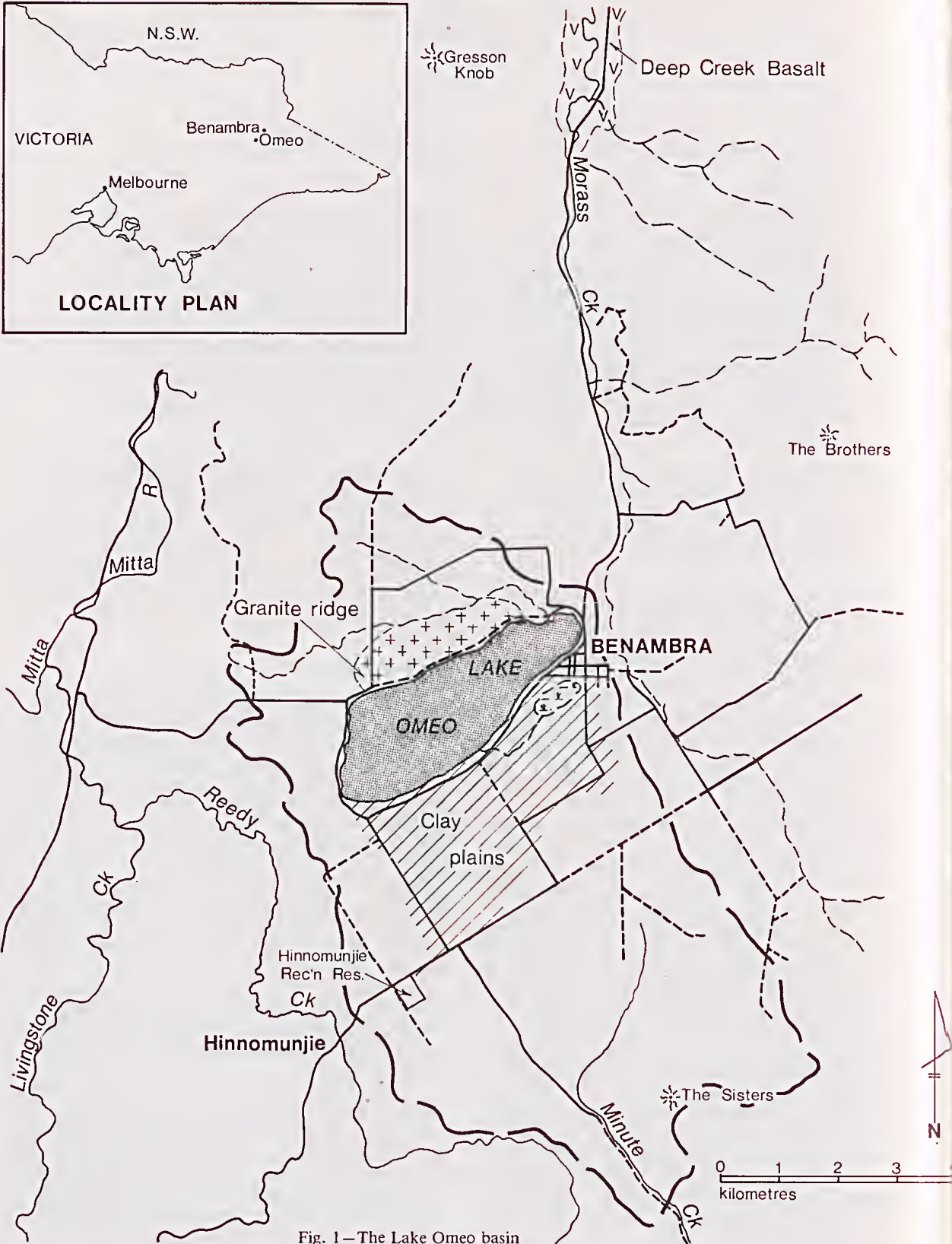


Fig. 1—The Lake Omeo basin



Fig. 2—The western end of Lake Omeo—1960.

as a small horst with its origin in the Pleistocene. He attributed damming of the lake to the horst.

Rowe (1967, p. 124) also associated faulting with the formation of the lake basin, and reported a considerable depth of alluvium in the basin so formed and the presence of two clay lunettes to the southeast of the lake, one being the lake-shore ridge (Fig. 4). The higher lake-shore or inner lunette forms a continuous ridge breached only by an ephemeral stream which includes the drainage of Minute Creek. The other lunette is south of the inner one and is lower and broken into several sections by local drainage (Fig. 5).

Both Thomas (1937) and Kenny (1937) referred to the basalt which blocked the early course of Morass Creek, and Thomas concluded that "Lake Omeo is thus a relic of a more extensive lake system". The basalt flow is referred to as the Deep Creek basalt as it is believed to have originated in the valley of that tributary of Morass Creek.

The streams have now incised the basalt to form a deep gorge and there is no ponding of water behind it except during flood flows, but before down-cutting commenced, water must have been ponded along Morass Creek for some 15 km and flooded the basin now occupied by Lake Omeo up to about the 715 m contour, the approximate level of the surface of the basalt. It is proposed to refer to this once extensive lake system as Lake Morass. Radiometric analysis of samples of the Deep Creek basalt resulted in two dates of 2.3 million years (Wellman 1974).

SUBSURFACE STRATIGRAPHY

Logs of bores sunk by a private contractor (M. Hob-

son, personal communication) in the 1940s and earlier, and of bores sunk under the supervision of the Victorian Department of Minerals and Energy in 1969, provide evidence of the subsurface materials. The locations of the Department bores are reasonably accurately known (Fig. 5) but others, except for the one in the north-eastern gap, have not been located in the field. Material from the Department bores is much disturbed but is useful in confirming the general grade of the material, its gross colour and the nature of coarse fragments.

Bores through the inner lunette, its lower slopes and the bed of the lake all indicate that grey or brown clays extend to beyond 40 m below the lake floor with occasional gravelly or stony strata, some of which contain useful water (Fig. 6). Water-bearing gravels were found at about 7.5 m below the level of the lake floor by several private bores in Benambra township, and at about 21.5 m in the clay plain south of the main lunette. Water was also found at about 33.5 m below the lake floor by Mines Department Bore Hinnomunjie No. 3. A private bore sunk on the western side of the north-eastern gap in the basin boundary struck rock at 9.1 m and a "waterbearing floor" at 18.3 m (M. Hobson, personal communication).

Water from one domestic bore in Benambra township contained 800 ppm total soluble salts at a time when water in the lake contained 2800 ppm (26/8/60) which seems to indicate a source other than a stagnant groundwater reservoir beneath the lake floor. The bore data indicate that the surface beneath the sediments is irregular and consists of granite in the north, and shales, which are present on the boundaries of the basin.



Fig. 3 — The Lake Omeo basin viewed from the southwest.

OTHER FEATURES OF THE BASIN

SANDY HIGH LEVEL BENCH

Coarse sandy sediments have been deposited by two streams which flowed into the lake from the north and west (Fig. 5). Sediments from the larger and more easterly stream extend toward the saddle in the basin boundary to the northeast, and beyond the southern edge of the granitic ridge to form a flat to gently sloping bench extending about 1.2 km along the southern flank of the ridge. The upper level of this bench is slightly below the level of the gap in the northeastern corner of the basin (Figs 7B and 8).

A 3-4 m deep excavation in the sandy bench near the northeastern corner of the lake, adjacent to the present course of the stream from the north, revealed several bands of silty material about 10 cm thick which dip in gentle curves towards the lake (Fig. 9).

The northeastern extension of the surface of the bench is clayey to a depth of more than 2 m and water accumulates in shallow depressions on it. A low levee has been constructed near the northeastern gap in the basin boundary to form a shallow dam. No such clay mantle exists over the southern part of the bench.

HIGH LEVEL FANS

Two large alluvial fans on the western slopes of the Benambra horst just south of the township (Fig. 5) have had their toes truncated at about the 700 m contour. Both fans have houses built on them.

LUNETTES

Two clay lunettes (Figs 5, 7, 8) on the southeastern side of Lake Omeo were recorded by Rowe (1967, p. 174). Several bores sunk through the inner lunette demonstrated that it consists entirely of clayey material. The results of particle size analysis of samples taken from a hole augured to 5.5 m in the top of this lunette (Fig. 11) are presented in Fig. 10. Clay contents of about 70 per cent are recorded generally below the surface 0.3 m, however, a horizon of only 45 per cent clay occurred between 3.0 m and 3.4 m from the surface. This corresponds approximately to the composition of the present surface soil and may indicate an earlier surface on which a soil formed.

The inner lunette is the higher and more continuous of the two. Its maximum height occurs near the centre of the ridge where its crest has an irregular, hummocky form (Fig. 11). It extends from the township of Benambra, where it merges with the horst of sedimentary rock, almost to the southern extremity of the lake where it gradually decreases in height to the level of the clay plain. It is breached by a small non-permanent stream which drains the greater part of the eastern half of the clay plain to the south of the lunette and includes the drainage of Minute Creek which has been channelled into a depression behind the lunette at the Benambra end. Drainage from the remainder of the southern part of the basin enters the lake at the southern end of the lunette.

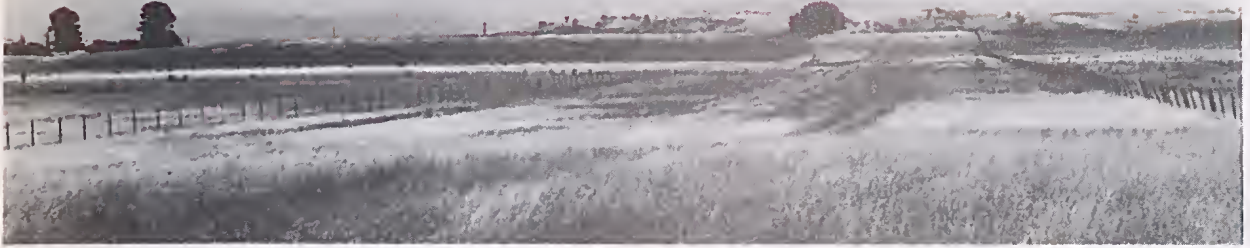


Fig. 4—The inner lunette viewed from the south. The much reduced outer lunette can be identified by the rise in the left-hand fence line.

Another noteworthy feature of the inner lunette is the presence, towards its eastern end, of a flat to gently concave bench sloping up from the lake side to the crest (Fig. 8). The flat part of this bench is at approximately the same level as the tops of the sand deposits on the northern shore.

The outer lunette is broken into three short sections by drainage channels at the general level of the clay plain between the two lunettes. The southwestern section is the highest and the lowest is the eastern section. There is no obvious evidence of this lunette having extended east of a line extending southeast of the breach in the inner lunette.

The general level of the clay plain to the south of the inner lunette is some 4 m higher than the floor of the lake as shown in Fig. 7A. A number of crescentic depressions to the south of the two main lunettes may indicate the presence of other low mounds of lunette-type origin. Level traverse C, (Fig. 7A) shows a rise in level to the south of the outer lunette which may be the truncated relic of another lunette.

BEACHES

Several beaches are cut in both the southern and northern shores of the lake. Two main beaches are shown in Fig. 7A and 7B. Each is gently sloping and up to 20 m wide and has abundant limestone gravel on its surface. Numerous other lap-lines exist on the lunette shore. The recent highest water level (circa 1956-57) coincides with the lowest of the prominent lunette-shore beaches on the southern side of the lake.

On the northern shore, which is dominated by the sand deposit described above, the remnant strandline morphology is less well preserved than on the clayey southern shore.

THE CLAY PLAIN

To the south of the inner lunette, and extending from the foot of the Benambra horst in the east to near the Hinnomunjie Recreation Reserve in the southwest, is a flat to gently sloping plain. The regularity of its surface is broken only by the low ridges of the remnants of the

outer lunette and shallow drainage depressions including Minute Creek and the swamp south of Benambra township. Its southern margin is indented by low bedrock ridges which extend north from the slopes of the Divide which forms the southern boundary of the basin (Fig. 1). The material forming the plain is clay, as indicated in a number of holes augured to examine the soils.

POSSIBLE OVERFLOW GAPS IN THE BASIN BOUNDARY

Dumpy-level traverses were run to several low gaps in the eastern boundary of the basin. The gap in the northeastern corner was the lowest with a relative level (above a local benchmark established for the purpose) of 34.1 m, but the gap to the southeast of Benambra school was only slightly higher, 34.3 m. The cross-sections of the northeastern gap (along the road) and school gap are shown in Fig. 12A, B. The contour map shows all these gaps as being below 700 m elevation (Fig. 5).

SOILS

SOILS OF THE CLAY PLAIN

Examination of soils by auguring in the southwestern corner of the clay plain, near the Hinnomunjie Recreation Reserve has revealed the existence of a soil buried beneath dark clayey sediments (SCA Profile 550 Appendices 1, 2).

The upper soil is generally a very dark brown to black clay, about 30 cm thick. It has a clear to abrupt boundary with a lighter coloured and lighter textured horizon which is the A-horizon of the buried soil. The buried soil is a duplex soil (Northcote 1979) with an abrupt and wavy boundary between the A-horizon and a heavy clay B-horizon varying from about 6 cm to 10 cm below the buried surface. The upper B-horizon of the buried soil has weak structure but below 55 cm the structure is strongly developed with 1-2 cm blocky to prismatic peds which are coated with thick black cutans.

SOILS OF THE LUNETTES

The soils on the inner lunette are dark clays with a

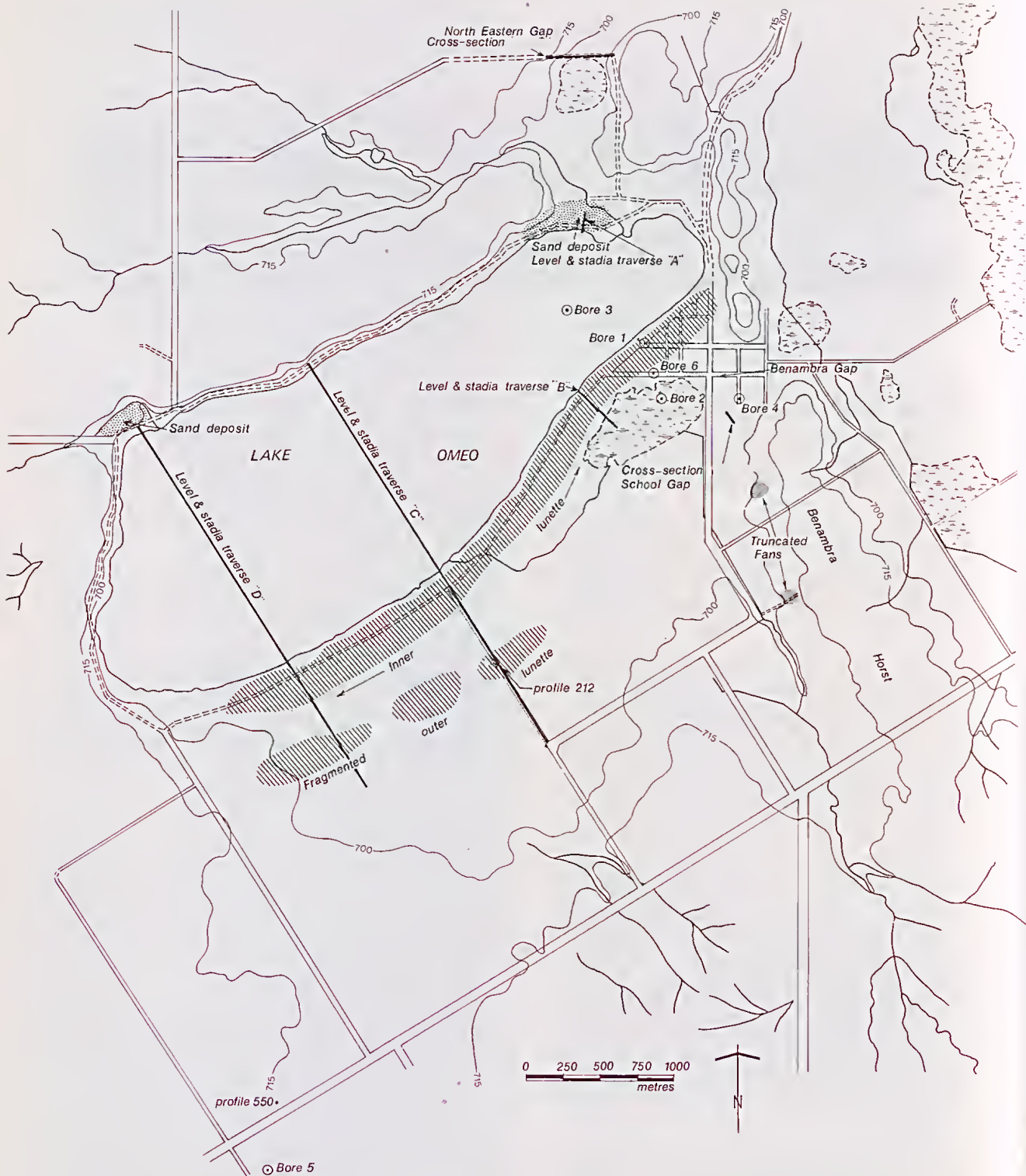


Fig. 5—Features associated with the Lake

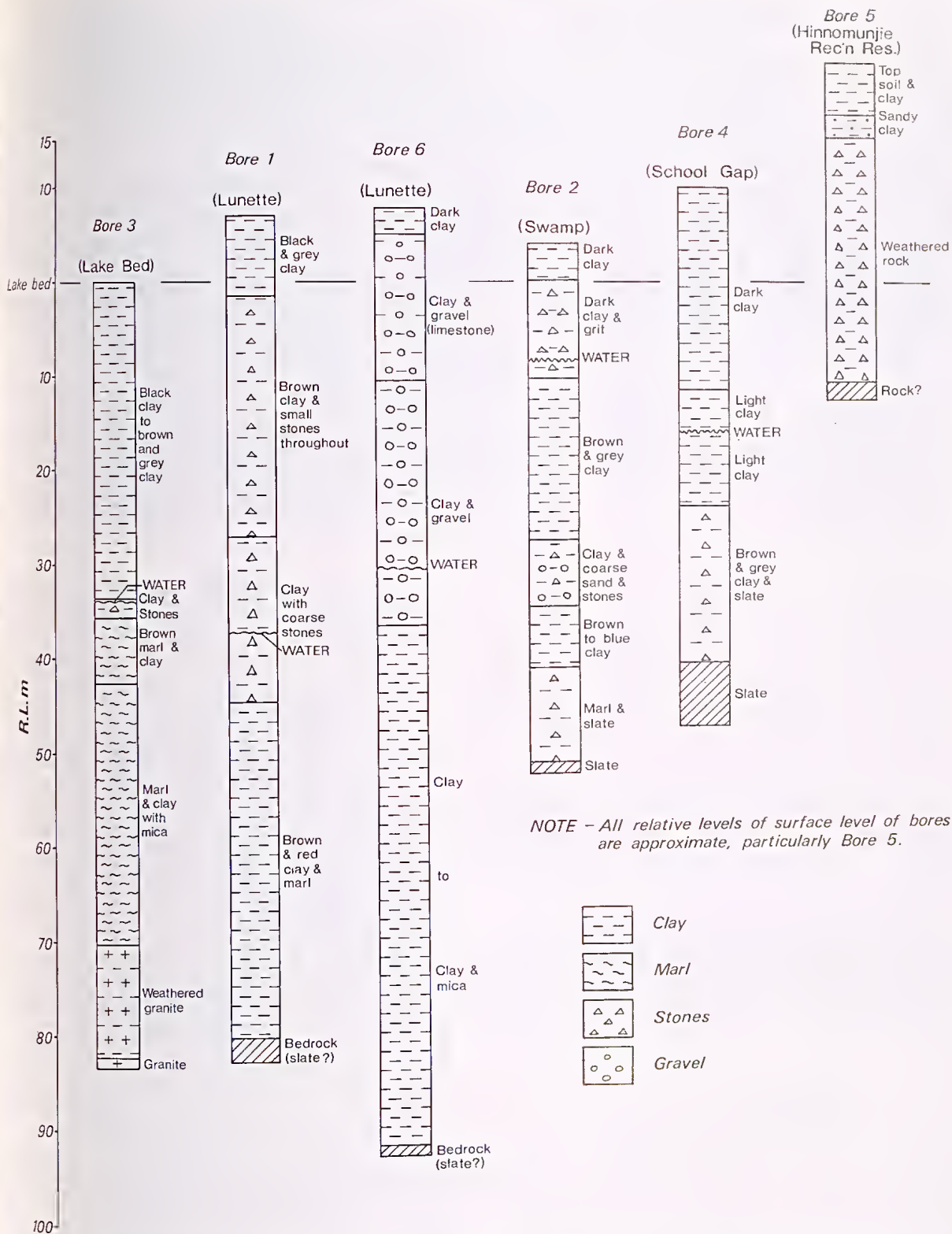


Fig. 6—Diagrammatic representation of bore logs from Lake Omeo. (Data from Department of Minerals and Energy, with permission).

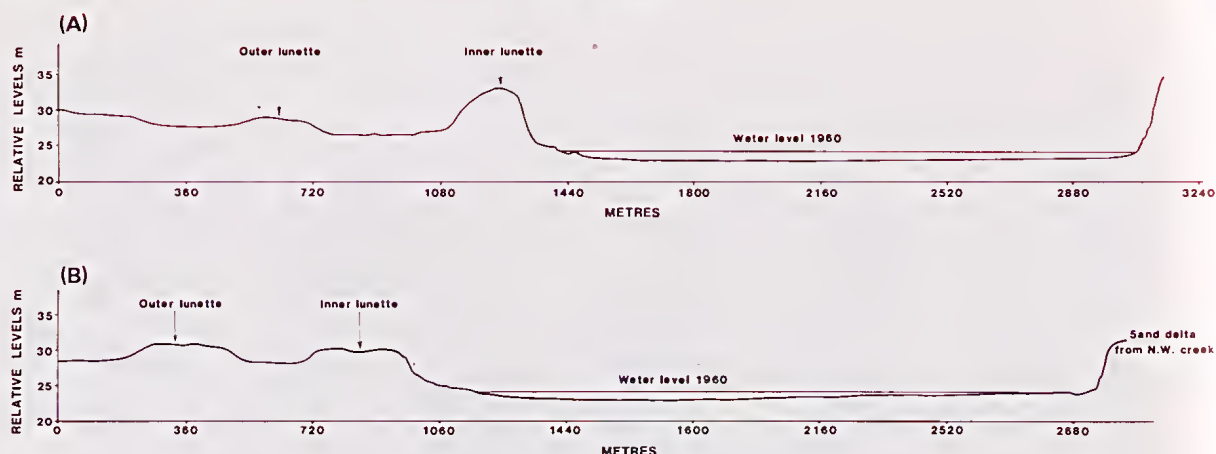


Fig. 7—A, Level and stadia traverse C
B, Level and stadia traverse D

strongly developed structure at the surface, becoming an olive-grey heavy clay with depth. They are neutral to slightly alkaline in the surface but become alkaline in the subsoil where free lime, either as soft or small hard concretions, is usually present.

A soil on the outer lunette (SCA Profile 212 Appendix 1) has a fine sandy clay loam to fine sandy clay surface which is strongly acid to acid and which at 15 cm depth abruptly overlies a dark clay which is slightly acid to neutral. The clay content increases until below depths of about 30 cm it remains consistently high (75 per cent) and the reaction rises to very alkaline (pH 8.4) (Appendix 2). Hard limestone concretions up to 10 cm diameter are present at about 70 cm depth. The surface 15 cm appears to be a separate layer of more sandy material.

THE SOIL IN THE NORTHEASTERN GAP

The soil in the bottom of the small dam is a dark cracking clay. Just beyond the low wall of the dam the soil is a weakly differentiated clay loam to clay to 80 cm below which is a dense clay with 1-2 cm blocky peds to 200 cm.

OTHER SOIL INFORMATION

The soils were examined along the road reserve which extends to the northeast of the site of the buried palaeosol. The surface soils on the sloping sides of the valley of Minute Creek and the Benambra horst (up to approximately the 715 m contour) were found to be

conspicuously darker and to greater depth than soils above that level.

INTERPRETATION OF DATA: THE SEQUENCE OF EVENTS

FORMATION OF THE LAKE OMEO BASIN AND LAKE MORASS

The regional landscape was of relatively low relief prior to the tectonic events which led to the formation of the basin. There are numerous relics of this landscape in the region—the low gaps in the Dividing Range at Tongio Gap and Cassilis Gap and small plateaux such as McMillans Lookout, and many of the hilltops between Omeo and Benambra.

Crohn (1950) described a fault along the Livingstone Creek which may have been a major cause of regional stream rejuvenation. The fault on the southern edge of the granite ridge which forms the northern shore of Lake Omeo (Thomas 1937), and the formation of the Benambra horst (Talent 1965, 1969) may also have occurred at this time. Talent (1969) proposed a Pleistocene age for this latter event. These faults formed the Lake Omeo graben with a down throw of some 70 m in the northeastern corner.

The blocking of Morass Creek by the Deep Creek basalt was more or less contemporaneous with or predated the rejuvenation of the regional drainage system as the landscape upstream has escaped the re-

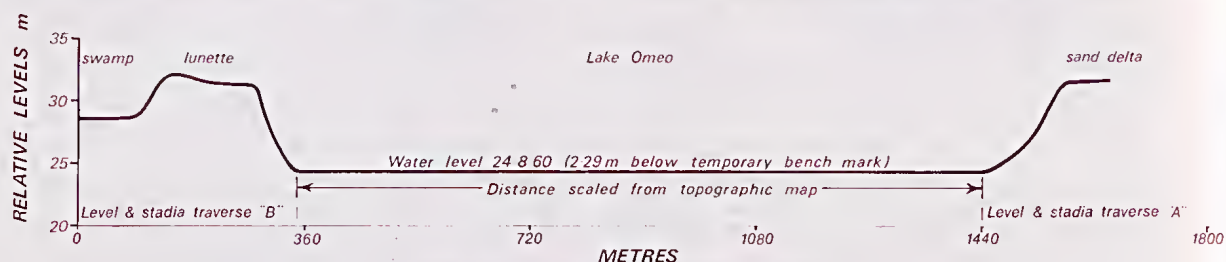


Fig. 8—Level and stadia traverses A & B.



Fig. 9—The sand deposit in the northeastern corner of the lake. Note the darker bands of silt.

juvenation. Radiometric dating of the basalt (Wellman 1974) places this event in the Upper Pliocene (2.3 my). Plugging of Morass Creek by the basalt resulted in the formation of an extensive lake, for which the name Lake Morass is proposed.

EFFECTS OF LAKE MORASS UP TO THE FORMATION OF THE MORASS CREEK GORGE

The great depth of clay revealed by the bores in and adjacent to Lake Omeo indicates a long period of accumulation during which the waters of Lake Morass flooded the basin to approximately the 715 m contour. However, during this period there was at least one drier period when there was little or no water in Lake Omeo. The presence of "stones" recorded in the bore logs (as distinct from "gravel", which in some instances at least are secondary carbonate nodules) indicates fluvial transport. Further clay deposition followed, indicating a return to high lake levels.

Several low gaps between Lake Morass proper and the Lake Omeo basin were also sites of clay deposition (see Bore 4—School Gap, Fig. 6). However, the lowest gap is that in the northeastern corner of the basin and its cross-section (Fig. 12A) seems to indicate that it did not carry eroding flows after the final decline of the level of Lake Morass, i.e. after Lake Omeo finally became independent of the Morass Creek drainage system. This does not deny the possibility that at some intermediate stage, eroding flows may have passed between the lakes, most probably flowing into Lake Omeo because of the larger catchment of the Morass. If this happened, sedimentation in the gap or wave levelling as the waters subsided would have tended to smooth the gap profile.

The coarse sandy deposit which extends beyond the northeastern end of the granite ridge is a delta formed by deposition in the high level Lake Omeo from the small stream draining the northwest of the basin. The thin gently dipping silt bands within the deposit mark changes in the depositional regime, probably periods of less erosion in the catchment when lacustrine deposition predominated over fluvial deposition by the stream.

The interpretation of the formation of Lake Omeo by sedimentation of the overflow gap (Kenny 1937) is therefore partly correct. If the small stream which drains the area north of the granite ridge had not been diverted to the south of the gap by its own sediment, it is probable that the northeastern gap would have been gradually lowered as the level of Lake Morass was reduced, and the waters of the Lake Omeo basin may have now drained through it.

There is, however, evidence of lacustrine rather than exclusively fluvial sedimentation in the northeastern gap. The soils in the bed of the dam in the gap are dark cracking clays and a hole augured just northeast of the dam wall encountered heavy, strongly pedal clay between 80-200 cm. This means that much of the sand deposit exposed on the lake shore postdates the isolation of Lake Omeo from Lake Morass or at least that the present day bench was cut after isolation.

Several alluvial fans on the western slope of the Benambra horst and at least one on the granite ridge have been truncated at about the level of the 700 m contour. No detailed levelling has been carried out on these features but it seems probable that the truncation was effected when the lake was below the maximum level of about 715 m. It is therefore proposed that the fans were

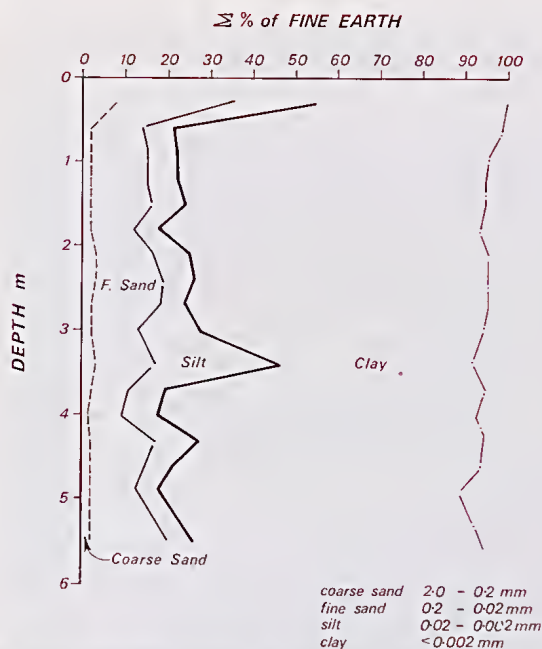


Fig. 10—Particle size analysis of a soil profile on the crest of the inner lunette.

formed during a relatively dry period (low lake levels) when surface erosion was prevalent, possibly related to a period of "stone" deposition on the basin floor. The fans were subsequently truncated upon the refilling of Lake Morass. That this was at about the 700 m level indicates that, by that time, the Morass Gorge had been incised some 15 m below the top of the basalt.

The Morass Creek gorge was eventually cut through the basalt and Lake Morass was drained. Until recently the course of the creek for several kilometres above the basalt was very swampy but it has now been artificially drained.

THE LAKE OMEO BASIN AFTER ISOLATION FROM LAKE MORASS

There is a lack of evidence to indicate what happened between the isolation of Lake Omeo and the formation of the "outer lunette". Low lake levels and conditions favourable for lunette formation must have prevailed for a considerable time to produce this lunette which has a base about 300 m across (Fig. 7B) at its widest. This lunette marked the southeastern shore of a lake, which may have been formed in that area by further slight down faulting of the graben.

Bowler (1980, 1983) has described the conditions required for lunette building. He rejects the effect of ice crystals in producing the clay aggregates on the basis of the lack of supporting evidence from Lake George. However, he emphasises the importance of salts, especially chlorides in the formation of clay aggregates.

The inner lunette has similar width of base to the outer lunette, and has for much of its length the typical dune form as is shown in level traverse C (Fig. 7A). The presence of pairs of lunettes such as this has been reported by others (Stephens & Crocker 1946, Campbell 1968) although no single explanation appears to satisfy all cases. In this case it seems likely that slight down faulting of the graben may have caused the ephemeral lake to contract, thus creating a new shore just north of the original lunette.

The size of the inner lunette is also such that a considerable period of lunette building was involved and the floor of the lake was eroded to some 4 m below the general level of the plain between the two lunettes.

A period of higher lake levels interrupted lunette building, and wave action truncated both lunettes to the form shown in Fig. 7B. The gentle northerly dip of the line of accordance across the lunettes on this cross-section suggests that further downward movement on the northern edge of the graben may have occurred subsequently.

Some reshaping of the surface of the sand delta by wave action is evident in level traverse B (Fig. 8) and from the extension of this bench along the northern shore of the lake at the foot of the granite scarp. The level of the bench is approximately 3 m below the level of the northeastern gap (the "overflow gap") which indicates that the high water level responsible occurred at a time when Lake Omeo was independent of the Morass Creek drainage system. However, it is accordant with the tops of the two lunettes (Fig. 7B) at the western end of the lake and with the bench at the eastern end of the inner lunette (Fig. 8).

Return of drier conditions led to resumption of lunette building on the inner lunette.

The bench at the eastern end of the inner lunette is, on present levels, at about the same level as the tops of the two lunettes at their western ends (Fig. 7B). However, the bench on the eastern end of the outer lunette is about 2 m lower and dips slightly more steeply than those at the western end (Fig. 7A).

The further down-faulting proposed above could have produced these differences. However, as the bench at the eastern end of the inner lunette is still at about the level of the benches at the western end (31 m), and this is

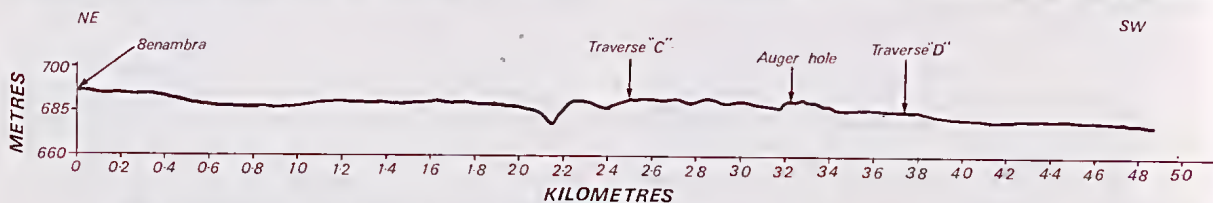
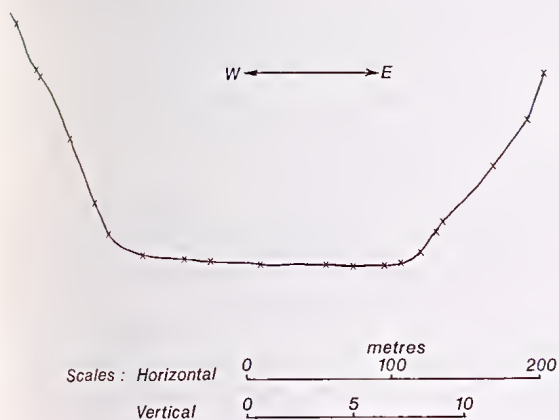


Fig. 11—Traverse along the road on the top of the inner lunette. (Aneroid barometer and car odometer.)

(A) Cross-section of north-eastern gap of Lake Omeo
(Lowest point Relative Level 31.1m)



(B) Cross-section of school gap of Lake Omeo
(Lowest point Relative Level 34.3m)

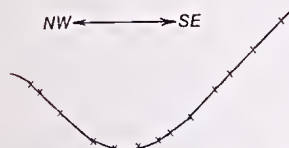


Fig. 12—Cross sections of the lowest gaps in the basin's boundary.

in accord with the bench on the sand deposit on the northern shore, it is proposed that another period of high lake level occurred and further wave shaping of the emergent inner lunette resulted. A period of lunette building between the two high lake phases, as above, was necessary to build the inner lunette above the level of the truncated eastern end of the outer lunette. The sand delta and bench would also have been reshaped by the second phase of high lake levels.

Return to drier conditions and renewal of lunette building mainly in the centre of the inner lunette, resulted in building up clay bodies with dune-form sections and an irregular crest line (Fig. 11). The small low ridge on the northern edge of the inner lunette on level traverse D (Fig. 7B) and the more typical lunette form on level traverse C (Fig. 7A) are the result of this renewed activity.

The particle size distribution study of the profile in the crest of the inner lunette shows a marked break in the sedimentary pattern some 3.5 m below the surface. This is at about the level at which the lunette would have been truncated if the hypothesised high lake level is correct.

The bench at the eastern end of the inner lunette appears to mark the last high water level in Lake Omeo. Several small beaches were identified by fairly detailed levelling close to the water level in 1960. These, no doubt, marked brief periods of climate wetter than that of the present.

INTERPRETATION OF THE SOILS EVIDENCE

The buried duplex soil near the southwestern edge of the clay plain is a very well differentiated soil and the overlying layer is clearly of different material. The uniformity and fine texture of this material (Appendix 2) suggests a lacustrine origin. The 715 m contour is drawn close to the site but may not be very accurately placed; however, the site appears to have been close to the margin of Lake Morass when at its highest level. The extensiveness of clay cutans on the voids in the buried soil and particularly their thickness on the structural units of the buried B-horizon suggest a long and/or efficient leaching of clay from the mantling sediments and periodic drying to form the cracks. This is consistent with shallow lake conditions where periodic inundation and drying out occurred.

It is not possible that the waters of the independent Lake Omeo reached this level because the natural overflow gaps are much lower. It is therefore proposed that the buried soil was at the surface prior to the formation of Lake Morass. It is thus a palaeosol dating from the Upper Pliocene. The 2.3 million year age for the basalt (Wellman 1974) provides a valuable dating for this soil.

The soil on the outer lunette is also two layered, however, that site is within the reach of high water in the independent Lake Omeo. The fine sandy texture of the surface layer is consistent with the washing of the finer particles from the characteristically clayey lunette material by wave action.

The large (10-15 cm), dense (marble-like) lime concretions at relatively shallow depth (70 cm) in the outer lunette are of interest. They are clearly the result of a long period of accumulation. Whether they formed during the lunette building phase when they may have been within the local watertable zone, or after the initiation of the inner lunette or at a later stage still cannot be determined. There is probably still a localised watertable near the surface of the clay plains despite the lake floor being up to 4 m lower, because of the poor drainage and heavy texture of the material. Therefore it is likely that carbonate accumulation is still occurring.

Bowler (1980, 1983) has argued the significance of the presence of a watertable at shallow depth in the formation of clay lunettes. It therefore seems very likely that the concretions started to form at the top of the watertable when the outer lunette was being formed. Careful sampling of carbonate from the centre of the larger concretions may provide material for C^{14} dating which could indicate the age of commencement of accumulation.

THE CLIMATIC SEQUENCE

The analysis of late Pleistocene climatic fluctuations in the Lake George basin of NSW (Coventry 1976) suggests that lower temperatures than at present, which reduced evaporation, were of more importance in establishing high lake levels than increased precipitation. In fact reduced precipitation may have occurred at the same time. Thus, the use of the terms wetter or drier

in this discussion refers to the relative balance between precipitation and evaporation and is relative to the current long term balance. In his study of mallee landscape development Bowler (1980) related the dune/lunette building phases to glacial periods and high lake levels to interglacials. Thus, the drier periods are assumed to have been colder and with lower precipitation whereas the wetter periods could have been so because of higher precipitation, lower evaporation or combinations of both.

The existence of fluvial material (stones other than calcareous concretions) within the clayey lacustrine sediments of the basin indicates that at least during one prolonged period during the existence of Lake Morass, the flooding of the Lake Omeo basin was periodic at most. There is a zone roughly 30–40 m below the lake bed in which stones are present in both Bores 1 and 3, and at similar depth in Bore 2 coarse sand and stones are present. Therefore at a time corresponding to about halfway through the period of lacustrine sedimentation a drier climate than that which kept the basin flooded prevailed for long enough to enable stones to be deposited through approximately 10 m of the sedimentary sequence. The fans on the western slopes of the Benambra horst may have formed at this time also.

At some period after the isolation of the Lake Omeo basin from the Morass Creek drainage, the climate was suitable for lunette building. The size of the outer lunette indicates a long period of such climate. Building of the inner lunette would have taken as long again. It has been proposed that the presence of two lunettes was caused by a change in the lake shape due to fault movement, and it is possible that the drier climate spanned the two lunette building periods; however, it is also possible that two major cycles of wet/dry conditions were involved.

The benches cut across the western ends of the two lunettes required a high level and a wetter climate. Return to the drier climate required for lunette building followed which resulted in further addition to the inner lunette.

Another lake-full period with wetter climate occurred during which the bench on the northern sand deposit and the bench at the eastern end of the inner lunette were shaped. A relatively short period of lunette building followed, resulting in redevelopment of the typical dune form in the central part of the inner lunette.

Subsequent climates have not caused sufficient change in geomorphic processes to have left clear evidence in the features of the basin. The sequences of small beaches on the lake side of the inner lunette indicate successively lower stands of lake level which may have occurred during the drying out after the last lake-full period. However, these beaches are still clearly defined and are probably relatively young. Therefore, a more recent period of higher than current lake level, but not as high as the major fillings referred to above is proposed. This could have resulted from a short period of wetter climate.

The present climate is such that in general the annual precipitation is less than evaporation so that the lake

only contains water in those infrequent periods when higher than average rainfall occurs over several years (Bennett & Schwerdtfeger 1970). Sufficient rainfall occurs for complete vegetative ground cover, even when there is insufficient to put water in the lake, so there is currently no evidence of lunette building.

A highly generalised diagrammatic representation of the climatic variation indicated by the land forms of the basin is presented in Fig. 13.

Bowler's (1980) analysis of palaeohydrology in the mallee regions of NW Victoria and SW New South Wales resulted in the postulation of several cycles of drier dune/lunette building periods and wetter periods when high lake levels prevailed. He is able to ascribe approximate ages to the various phases by means of radiocarbon dating of material representing the more recent events and by correlation of the inferred palaeohydrologic conditions with glacial/interglacial chronology established elsewhere and the palaeomagnetic reversal for the earlier events.

The only absolute date available from this study is that of the basalt flow (2.3 my: Wellman 1974) which marks the starting point for the features described in this paper. Thus the Lake Omeo land forms come within the age scale proposed by Bowler for the Mallee areas, and as he considers that the climatic changes involved were of global significance it is tempting to try to correlate the proposed climatic variations interpreted from the Lake Omeo evidence with those proposed by Bowler for the Mallee.

The simplest interpretation is to relate the high beaches on the inner lunette to the cliffing at Lake Frome and Lake Tyrrell (10 000 yr BP), the last lunette building phase to the Mungo–Zanci Arid Period (25 000 to 15 000 yr BP) and the last major lake full period to the Mungo Lacustral Phase (50 000 to 25 000 yr BP.). However, the small magnitude of the younger features at Lake Omeo may mean that these three periods should be shifted back one cycle to correspond with the last two lake full periods, with the intervening lunette building period. This interpretation is presented in Fig. 13.

CONCLUSIONS

Although considerable evidence of the sequence of development of the natural features of the Lake Omeo basin is presented, there are many gaps and no doubt more field work would help to overcome this. Some of the hypotheses of renewal of down faulting and the shaping of the lunettes and other sedimentary land forms by high levels in Lake Omeo depend on the precision of the level traverses. Additional detailed levelling would be needed to check some of these. However, in general, differences in levels required to support the hypotheses are of the order of 5–20 m. The existing level surveys are well within that order of accuracy, but in some instances contour mapping has had to be relied upon and this presents problems in an area of such low relief. Even so, the degree of confidence in their level of accuracy seems reasonable.

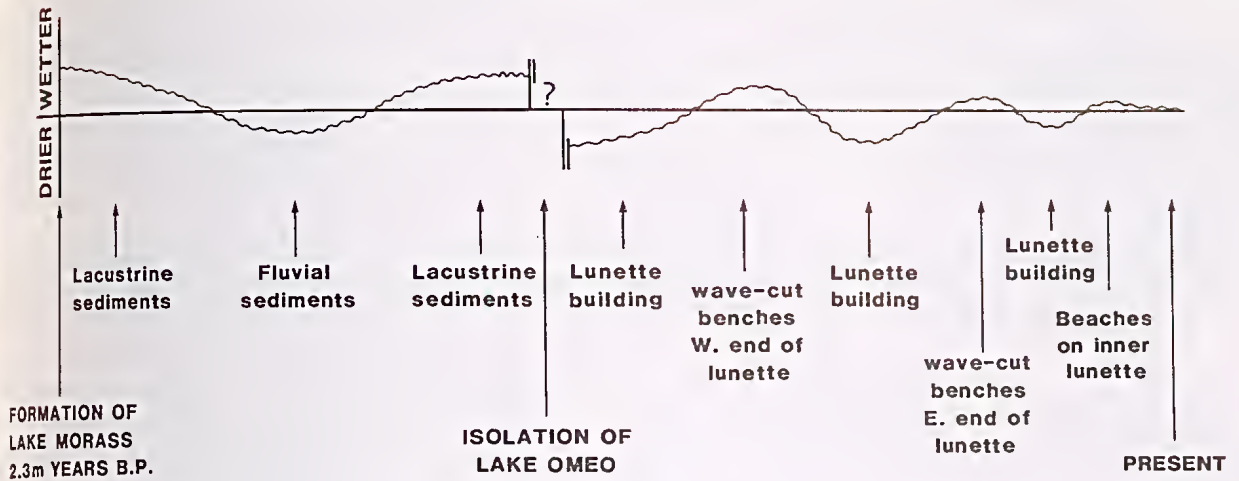


Fig. 13—Generalised representation of climatic variation as indicated by land forms of the Lake Omeo basin.

The climatic sequence proposed, though very broadly sketched, reflects patterns of change proposed by others (e.g. Bowler & Hamada 1971).

The significance of the evidence of the antiquity of some of the soils requires further consideration. Pedologists have generally agreed that the well differentiated duplex soils are very old but the extreme age indicated here is of great interest. The geomorphic-pedogenetic frame work proposed in an area to the north (van Dijk & Rowe 1980) supports the existence of soil materials of considerable age in the present day landscape, however, the inferred age of the buried soil from Lake Omeo is extreme. The area presents a unique opportunity where a soil of great antiquity has been preserved from erosion while elsewhere in the highlands there was substantial landscape dissection and surface stripping.

Of the period between the final isolation of Lake Omeo from Lake Morass and the building of the outer lunette, there is no geomorphic evidence. Nor is there any indication of the length of time required for lunette building. Radiocarbon dating of the marble-like concretions from the outer lunette may not be capable of indicating their true antiquity for they may well have originated beyond the range of the technique.

Because the Lake Omeo Basin is an area of internal drainage and has escaped the rejuvenation which has affected much of the region, many fossil features are preserved. It could still be a most fruitful area for further study. Radiometric and palynologic studies would no doubt prove worthwhile.

ACKNOWLEDGEMENTS

Field work on this study extended over a number of years and in that time the various level surveys have been carried out with the able assistance of A. S. Rundle, J. C. W. Langford and R. Smith for which I am thankful. Constructive and encouraging criticism by Dr J. M.

Bowler of the A.N.U. of early drafts of the manuscript were greatly appreciated.

Most of the field work and all of the typing and drafting of figures for the paper were carried out at the Soil Conservation Authority of Victoria; the willingness of the Authority to promote this study and approval for publication of the paper are gratefully acknowledged.

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APPENDIX 1 MORPHOLOGY OF SOIL PROFILES

Description of two-layered soil from clay plain near Hin-nomunjie Recreation reserve.

SCA Profile No. 550

0-10 cm	very dark brown (10 yr 2/2 moist) clay; moderate, 0.5-2 cm subangular blocky structure; clear smooth boundary
10-30 cm	black (10 yr 2/1 moist) light clay; weak to moderate, 0.5-2 cm subangular blocky structure; clear smooth boundary
30-36 (40) cm	light brownish grey (10 yr 6/2 moist) loam; apedal; abrupt wavy boundary
36(40)-55 cm	mottled black and dark yellowish brown (10 yr 2/1; 4/4 moist) heavy clay; weak, 2 cm blocky to prismatic structure; gradual boundary
55-82 cm +	mottled black and olive brown (10 yr 2/2; 2.5 y 4/4 moist) heavy clay; strong, 2 cm blocky to prismatic structure

SCA Profile No. 212

0-7 cm	black (10 yr 2/1 moist) fine sandy clay loam; moderate, 0.5-4 cm angular blocky structure; clear smooth boundary
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7-15 cm	black (10 yr 2/1 moist) fine sandy light clay, moderate, to strong, 0.5-4 cm angular blocky structure; clear smooth boundary
15-30 cm	mottled black and dark yellowish brown, heavy clay; strong, 0.5-1 cm angular blocky structure; weak clay cutans; occasional 1 cm carbonate concretions; clear smooth boundary
30-60 cm	mottled black and dark yellowish brown, heavy clay; strong, 1-5 cm blocky peds arranged in columns; well developed clay cutans; occasional 2 cm carbonate concretions; clear wavy boundary
60-100 cm +	mottled olive brown and black, heavy clay; strong, 0.5-2 cm subangular blocky peds weakly arranged in columns; well developed clay cutans; carbonate concretions up to 25 cm common—decreasing below 100 cm.

APPENDIX 2 PARTICLE SIZE ANALYSIS OF SOIL PROFILES

(1) SCA Profile No. 550

	Sand			
	Coarse	Fine	Silt	Clay
0-10 cm	5	29	22	44
10-20 cm	10	35	21	31
20-30 cm	12	38	24	27
30-40 cm	12	43	28	17
40-55 cm	5	18	9	66
55-75 cm	6	25	15	54

(2) SCA Profile No. 212

0-7 cm	11	36	17	27
15-30 cm	6	22	6	58
120-150 cm	1	11	9	74